NON-PERPENDICULAR IMPACTS - AN EXPERIMENTAL STUDY ON CRASH HELMETS

Bertil Aldman, Björn Lundell, Lennart Thorngren
Department of Traffic Safety, Chalmers University of Technology
Gothenburg, Sweden

ABSTRACT

In two-wheel vehicle accidents, the head of the occupant in many cases may hit the ground with a horizontal velocity. Due to friction, this can result in angular accelerations of the head which may prove to be injury-producing.

A test method has been developed with the purpose to investigate the effect of different helmet shell materials on the kinematics of the head at impact.

The test device utilizes a dummy head and neck attached to a rail-guided free-falling carriage. Simulated road surfaces can be attached to a rotating disc. Linear and angular head accelerations in three perpendicular directions as well as rotation and lateral flexion of the neck have been recorded.

Results from a preliminary test series are presented with reference to some published tolerance levels.

INTRODUCTION

Tolerance levels for linear head accelerations as expressed e.g. in the Wayne State Tolerance Curve and different injury criterias such as the HIC, have reached some degree of general acceptance.

Head angular accelerations have been less extensively studied. Some tolerance levels have, however, been published. These often give both a maximum angular acceleration and a maximum change in angular velocity (fig 1).

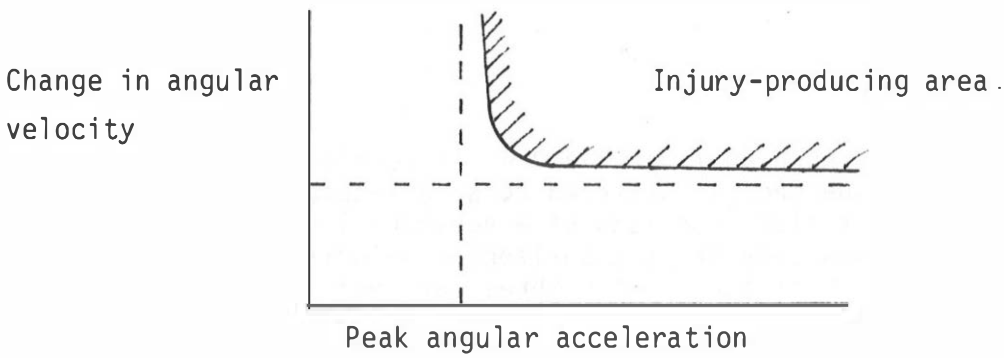

Fig. 1. Tolerance levels for head rotation.

Ommaya et al in 1967 (1) stated that 7500 rad/s^2 with 99% probability produces cerebral concussion and in 1971 (2)that greater accelerations than 1800 rad/s^2 and changes in angular velocities above approximately 60-70 rad/s will probably result in cerebral concussion. Both these levels were calculated from primate tests.

Tests with human volunteers performed by Ewing et al (3) indicate that man can withstand up to 1700 rad/s^2 without damage. In these tests the peak angular velocity did, however, not exceed 32 rad/s.

Löwenhielm (4) suggests tolerance levels of 4500 rad/s^2 and 50-70 rad/s. These levels were calculated from cadaver crash tests performed by Voigt and from a mathematical brain model.

The lowest tolerance levels published are thus 1800 rad/s^2 and 50 rad/s.

The fact that the knowledge about the tolerance levels for angular accelerations is limited is reflected in the safety regulations of different countries regarding car passenger restraints, motorcycle crash helmets etc. These regulations contain almost exclusively only safety criteria associated with linear accelerations.

There are, however, many types of accidents in which high values of angular accelerations may occur. One such type is accidents with two-wheel vehicles, where the risk is great that the occupant´s head hits the ground with a horizontal velocity component, this apart from linear accelerations may also result in angular accelerations of the head.

The danger of head angular accelerations may not only concern the head itself, but the subsequent flexion of the neck caused by the angular velocities attained during impact may become injurious. Also, the combination of angular and linear accelerations may be injury-producing.

We have developed the test method described in this paper to investigate how different helmet shell materials affect such variables as linear and angular accelerations of a dummy head.

Later on we intend to make validation tests by performing free-fall drop tests with a complete dummy.

METHOD

Introduction

The test device is shown in fig 2,3 and 4. It consists of an instrumented dummy head and neck. The neck is attached to a rail-guided vertically moving carriage. The road surface consists of a horizontal ring which rotates around a vertical axis, thus creating the horizontal velocity component. Linear and angular accelerations of the head in three perpendicular directions and lateral flexion and rotation of the neck are recorded during impact.

The test method intends to simulate the actual case when a helmeted person hits the road surface more or less simultaneously with his head and chest as the body slides along the road.

Dummy head and neck

The dummy head and neck from an Ogle-Opat crash test dummy is used. The lower end of the neck is attached to a rail-guided carriage, see figs.2 and 3. It is possible to orientate the head in almost any desired position in relation to the road. The weight of the instrumented head is 5.00 kg and of the neck 1.25 kg. The flexion characteristics of the neck are approximately 55 Nm/rad in rotation and 90 Nm/rad in flexion.

The neck is mounted on a plate which is hinged on the carriage upon a horizontal axis which during impact is almost at the same level as the road surface. This arrangements does not seem to affect the realism of the neck behavior during impact, and only slightly so after impact. Multiple helmet impacts are prevented by a locking mechanism on the mounting plate (fig. 2).

A lead cone is used to decelerate the carriage over approximately the same distance as the helmet uses to decelerate the head. In this way the influence of the carriage on the impacting head is minimal.

The downwards flexion of the neck before the carriage is dropped is neutralized by a thin wire leading from the nose of the head to the carriage. This wire is automatically released during the free-fall sequence.

Road surface

The road surface consists of a horizontal ring with an outer diametre of 1 metre and an inner diametre of 0.8 metres, see figs. 2 and 3. It rotates around a vertical axis. Each different surface material is glued to a 19 millimetre wood particle board, which on the test device is supported by a 10 millimetre steel disc. The steel disc is bolted to a hub taken from a lorry wheel. The wheel axle is securely bolted to the floor. The rotating surface has the disadvantage that the velocity is neither parallell nor constant over its surface, but within the relatively small impact area the difference from a completely parallell movement is very small.

The hub is rotated by means of an electric motor allowing any desired speed of the road surface up to more than 50 km/h at the radius of impact.

The disc is supported by a hard-rubber roller below the point of impact which increases the stiffness of the road surface so that the influence of the road surface deflection on the measured accelerations is small.

A polyurethane based glue (Casco 1820-1821) is used to glue stone material to the wood particle boards. The glue is mixed with fine-grain sand to obtain suitable viscosity of the glue during preparation.

Recordings

The recordings include linear and angular accelerations of the head in three perpendicular directions as well as lateral flexion and rotation of the neck.

The accelerations are measured by two tri-axial accelerometers, Kyowa AS-200TA and one angular accelerometer, Endevco 7301, see fig. 4. The accelerometers are placed on a mount with a natural frequency considerably above the upper frequency of the accelerometers. The linear accelerometers are placed 66 millimetres apart symmetrically about the center of gravity with a common G_y-axis. Thus it is possible to calculate two of the angular accelerations:

$$\dot{R}_x = \frac{a_z\text{, left} - a_z\text{, right}}{d} \quad , \quad \dot{R}_z = \frac{a_x\text{, left} - a_x\text{, right}}{d}$$

where a is the acceleration and d is the distance between the accelerometers. These calculations are performed by a simple analog computer. The rotational accelerometer is placed so that R_y is measured.

The end of the neck that is fastened to the carriage is equipped with straingages so that the torsional moment and the lateral bending moment may be measured. These moments are directly translatable into degrees of head rotation and lateral flexion. Due to the fact that the part of the neck to which the strain ganges are glued is not particularly suited for this purpose, the output is not very accurate, with a maximal error of about 10 degrees.

The following instruments are also used:

- Transducer amplifier, Betatron 8008, 12 channels
- Tape recorder, Philips Analog 14, 14 channels
- Low-pass filter, Kronhite 3200
- Analog computer, Tektronix AM 501
- Waveform recorder, Biomation 1015, 4 channels
- Oscilloscope, Tektronix 7603
- X-Y-plotter, Hewlett-Packard 7044
- High speed camera, Locam 51-0002, 500 frames/sec

After each test, the impact site of the helmet is photographed, and notations are made on all visible damage (figs. 6-9).

RESULTS

After the initial check out, a test series was carried out with 6 different helmet types and 6 different road surfaces. All the helmet makes used had the same type of liner made of expanded polystyrene. The shell materials differed in the following way: one had a fiberglass reinforced polyester shell, two had polycarbonate shells and two had shells of ABS combinations. Definitions of linear and angular accelerations is made in fig. 2.

The road surfaces used in this series were:

- No 1: A coarse grinding cloth (Naxos CKRG 20) glued to a wood particle board
- No 2: A Clean wood particle board, i.e. a smooth surface

- No 3: 12 mm angular stones glued to a particle board
- No 4: 4-2 mm angular stones glued to a particle board
- No 5: 12 mm subangular-round stones glued to a particle board
- No 6: Surface No 5 with a thin layer of oil applied.

Surfaces no 1 and 2 were selected to represent one very high-friction and one very smooth surface. Surfaces no 3-6 were intended to simulate different types of actual road surfaces: no 3 and 4 unworn surfaces, no 5 and 6 polished surfaces. How realistic these surfaces are is not yet clear.

During the main series of tests the head was placed with the sagittal plane vertical and with the neck inclining 24 degrees backwards from the horizontal plane, the position shown in figs. 2 and 3. The horizontal velocity was 8.33 m/s (30 km/h) with the road surface moving perpendicular to the sagittal plane from right to left and the vertical velocity 5.18 m/s (drop height 1.37 m).

Results from these tests are shown in fig. 5. The acceleration graphs have been filtered with a 1650 Hz low pass filter (SAE channel class 1000) and the angular displacement graphs with a 165 Hz low pass filter. Angular and linear accelerations are shown in tables 1 and 2. The resultant accelerations are somewhat greater than the ones shown in these tables. (See page 9)

A smaller test series was also carried out with the horizontal velocity parallell to the sagittal plane, the road surface moving from foot to head and also from head to foot. R_y in these tests did reach 14000 and 4500 rad/s^2 respectively.

Another test series was performed to investigate the influence of different drop heights and horizontal velocities.

Yet another test series was performed with a head and neck from a Sierra 1050 dummy. Results from these tests will be published in a later report.

Test have been made with different means of reducing friction between helmet and head, e.g. by using synthetic hair on the dummy. These tests show that helmets that are not over-size produce almost the same angular accelerations both with and without friction-reducing means in the test situation reported here.

For three tests with the polycarbonate make I helmet against surfaces no 3, 4 and 6, representing "typical" low, medium and high angular acceleration tests, some further results are shown in table 3.

CONCLUSIONS

The main purpose of this report is to describe a new test method for assessment of shock absorbing and friction characteristics of crash helmets. Some results from a first test series are, however, also reported because we find them most notable. We would like, however, to emphasize that the results are very preliminary and that more detailed tests will be carried out before more definite conclusions can be drawn.

The peak angular accelerations range from 4500 to 14500 rad/s^2, and peak angular velocities from 20 to 55 rad/s. It seems reasonable to believe that higher values for both angular acceleration and angular velocity may occur at higher impact velocities. Published tolerance values may therefore well be exceeded in similar accident situations. This suggests that some of the shell materials used today may well be too soft to provide a desirable low friction between helmet and road surface.

The linear deceleration pulses show little variations. They often lie only slightly below or above the Wayne State Tolerance Curve. HIC-values in most cases come close to 1000. It is notable that peak angular and linear accelerations occur simultaneously.

The realism of the method should be further investigated, both by performing free-fall drop tests of a complete dummy and by trying other road surface materials.

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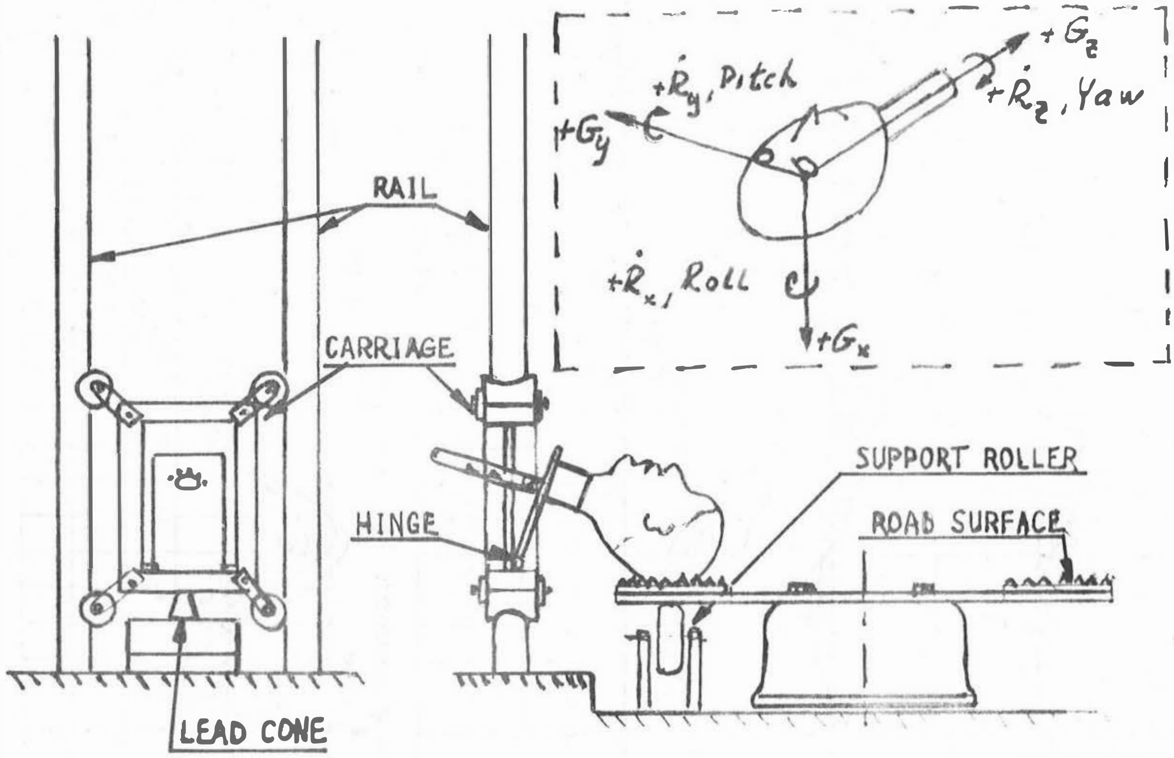


Fig. 2. Test device and acceleration definitions.

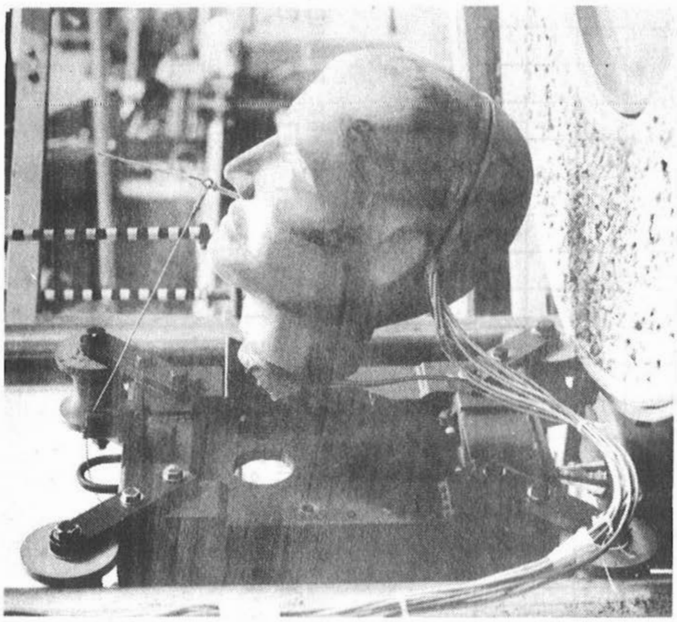


Fig. 3. Head and carriage

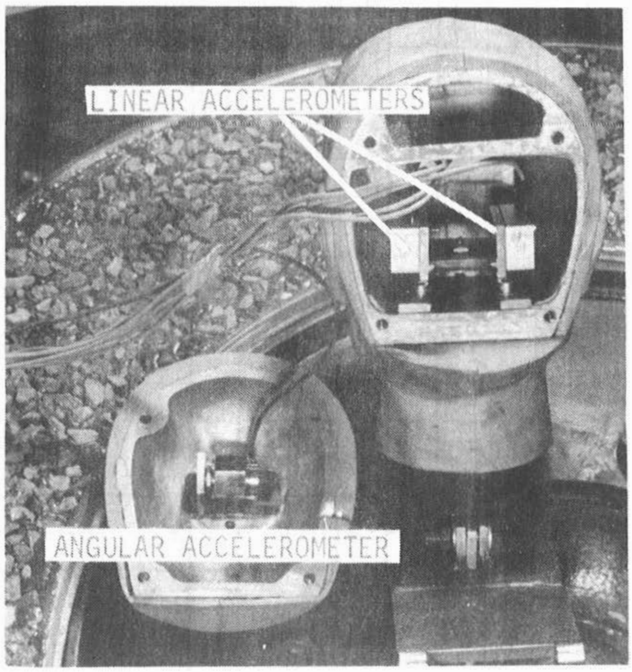
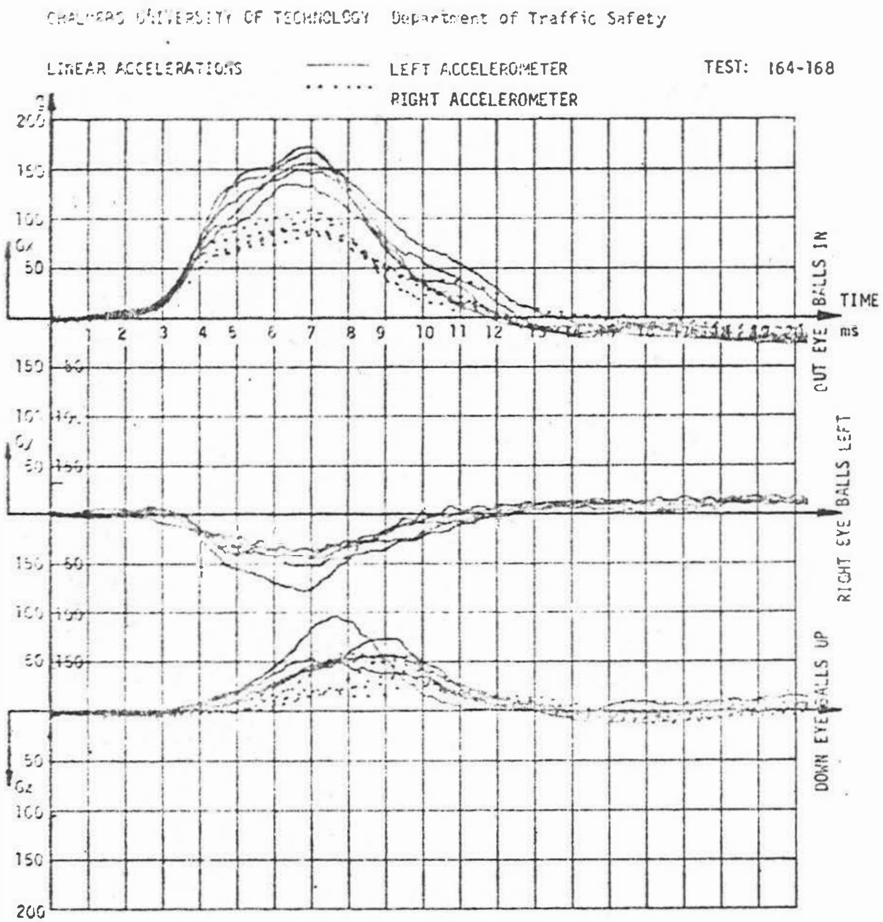


Fig. 4. Accelerometers inside head



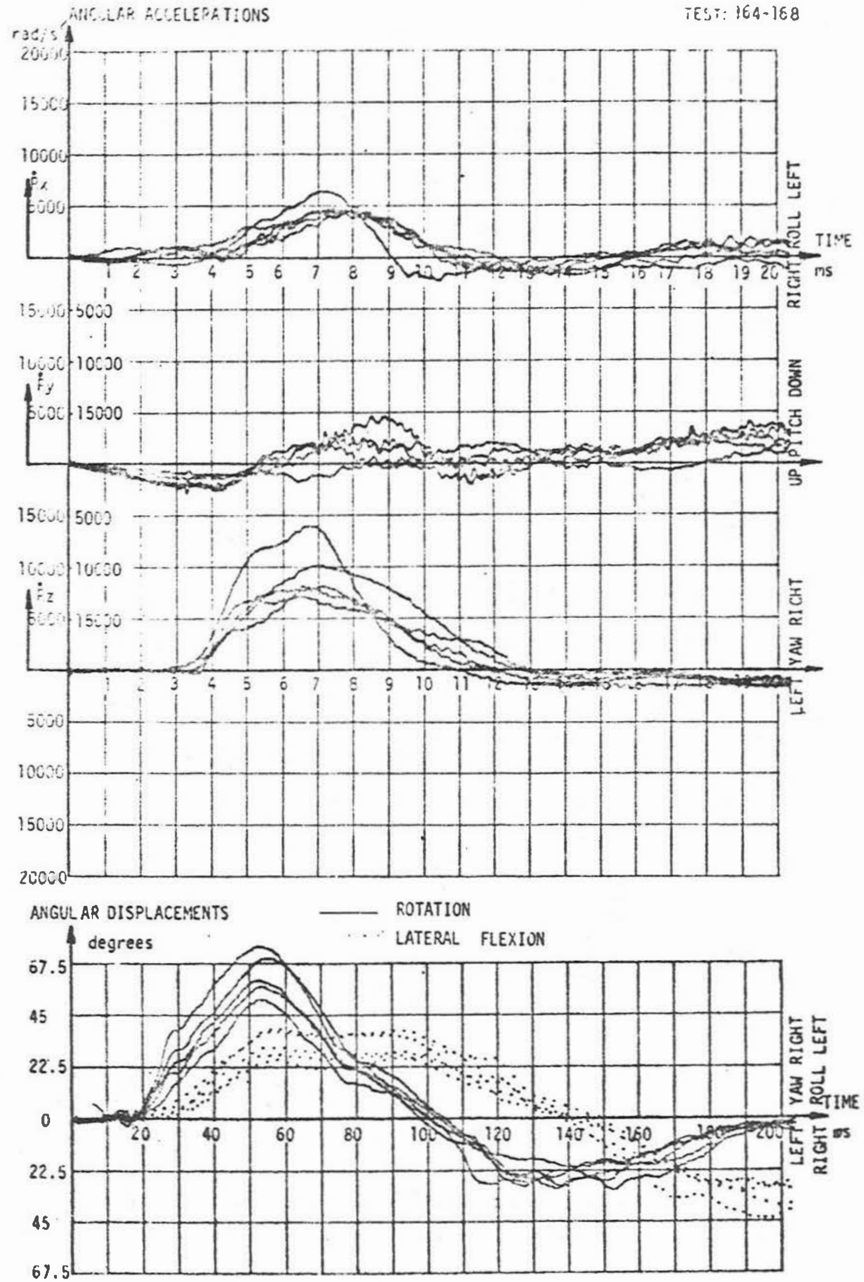


Fig. 5. 5 tests with 4 mm angular stones and different helmets. Horizontal velocity 8.3 m/s. Vertical velocity 5.1 m/s.

Table 1. Peak angular accelerations $\dot{R}_z$ rad/s^2. Vertical velocity 5.1 m/s. Horizontal velocity 8.3 m/s.

Helmet type \ Surface	No 1	No 2	No 3	No 4	No 5	No 6	Mean value	Standard deviation
Fiberglass make I	13000	7000	9000	7000	7000	6000	8200	2560
Polycarbonate m I	13000	7500	13500	8000	7500	4500	9000	3520
Polycarbonate m II	12500	8000	10000	9500	5500		9100	2580
ABS make I	13000	9000	11000	8000	9500	6500	9500	2280
ABS make III	13500	8000	7500	14500			10900	3640
Mean value	13000	7900	10200	9400	7400	5670		
Stand.deviation	350	740	2250	2990	1650	1040		

Table 2. Peak linear acceleration G_x g´s. Vertical velocity 5.1 m/s. Horizontal velocity 8.3 m/s.

Helmet type \ Surface	No 1	No 2	No 3	No 4	No 5	No 6	Mean value	Standard deviation
Fiberglass make I	110	125	90	115	90	95	104	15
Polycarbonate m I	120	130	135	130	120	105	123	11
Polycarbonate m II	115	125	90	115	90		107	16
ABS make I	130	135	120	120	130	115	125	8
ABS make III	135	135	115	130			129	9
Mean value	122	130	110	122				
Stand.deviation	10	5	18	8				

Table 3. Three typical tests (Polycarbonate make I helmet).

Road surface	Peak G_x g	Peak $\dot{R}_z$ rad/s^2	Peak R_z rad/s	Max HIC[1)]	Peak rotation degrees	Peak flexion degrees
No 6	105	4500	23	450	35	20
No 4	130	8000	40	800	55	34
No 3	135	13500	54	1030	80	45

1) calculated from resultant acceleration

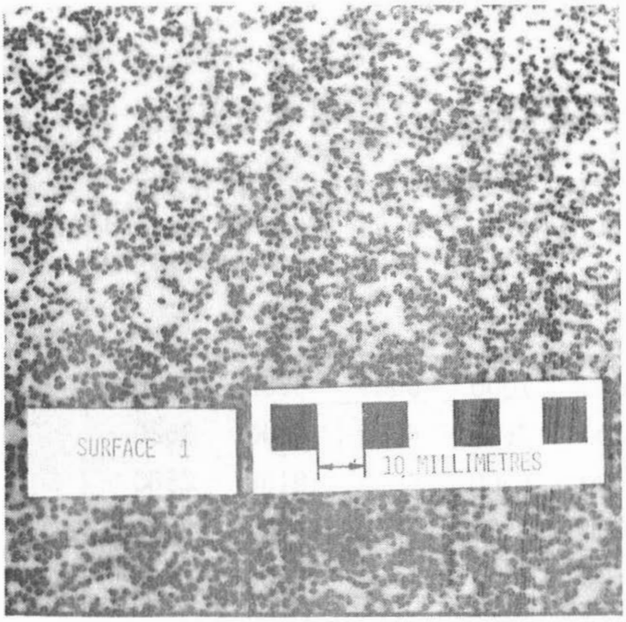


Fig. 6. Road surface no 1

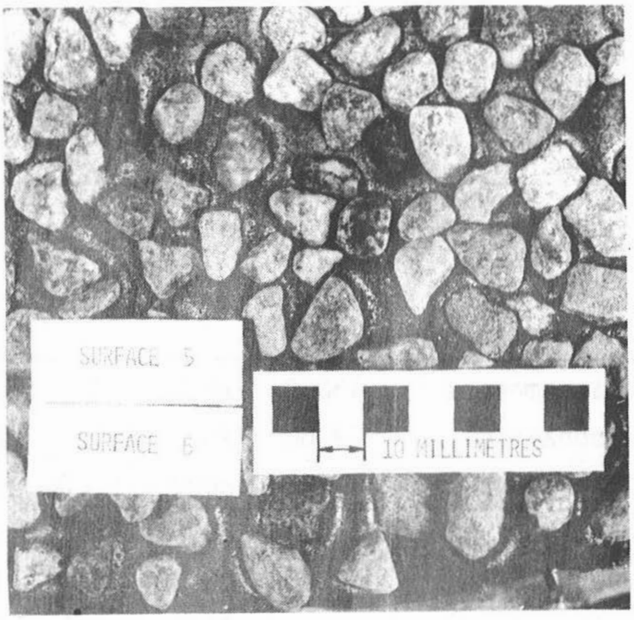


Fig. 7. Road surface nos 5 and 6

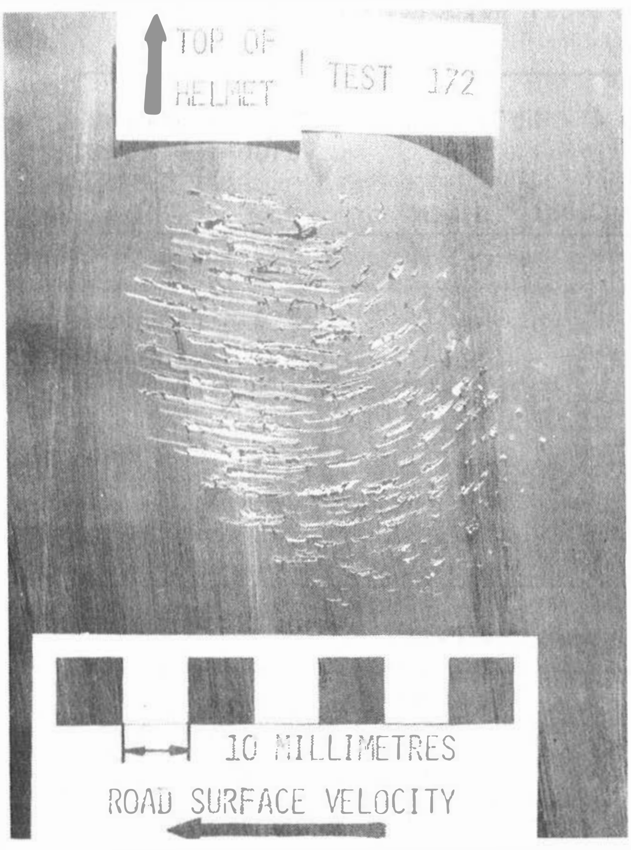


Fig. 8. Helmet damage from road surface no 1. Fiberglass shell

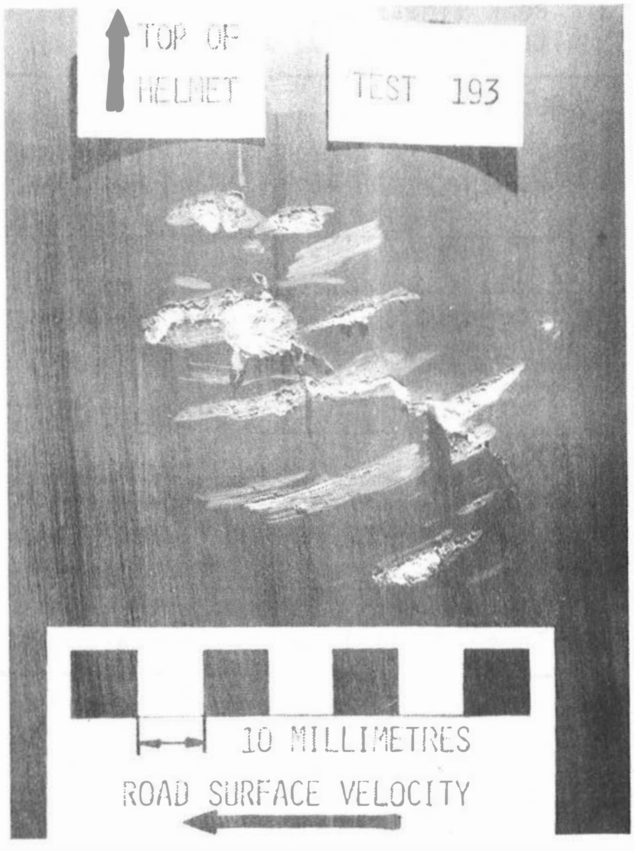


Fig. 9. Helmet damage from road surface no 5. Fiberglass shell